Exam in power electronics
2016-05-30 08-13

Means of assistance:	Calculator	
Grades:	20-30 p:	3
	31-40 p:	4
	41-50 p:	5
In total	5 exercises	

1 The 3 phase rectifier and buck converter

a) Draw a 1QC DC DC buck converter with a three phase diode rectifier connected to the power grid. The dc link capacitor and protection against too high inrush currents should be included in the drawing. (1 p.)

b) The three-phase grid, to which the three phase diode rectifier is connected, has the line-to-line voltage 400 V_{rms} and the frequency 50 Hz. Calculate the average and the maximum output dc voltage from the rectifier. (1 p.)

c) Calculate the rms-current and the average current through one rectifying diode (see figure 1). Calculate the rectifier diode losses. The diode threshold voltage is 1.1 V and the differential resistance is 2.0 mohm. (2 p.)

d) Calculate the transistor and the diode losses in the buck converter.
The voltage on the low voltage side of the buck converter is 430 V_{dc}. The switching frequency is 2.5 kHz. The buck converter inductance is 0.5 mH, its resistance can be neglected.
The threshold voltage of the transistor equals 1.4 V and its differential resistance equals 1.0 mohm. The turn-on loss of the transistor equals 60 mJ and its turn-off loss equals 80 mJ. These turn-on and turn-off losses are nominal values at 900 V dclink voltage and 180 A turn-on and turn-off current.
The threshold voltage of the diode equals 1.6 V and its differential resistance equals 1.5 mohm.
The diode turn-off loss equals 25 mJ, and its turn-on loss can be neglected.The diode switch losses are nominal values at 900 V dclink voltage and 180 A turn-off current. (4 p.)

e) Which is the junction temperature of the transistor and of the diode, and which is the junction temperature of the rectifying diodes?
The thermal resistance of the heatsink equals 0.05 K/W?
The thermal resistance of the transistor equals 0.1 K/W?
The thermal resistance of the diode equals 0.2 K/W?
The thermal resistance of the rectifier diode equals 0.15 K/W?
The ambient temperature is 35 ºC.
The rectifier diodes and the buck converter transistor and diode share the heatsink. (2 p.)

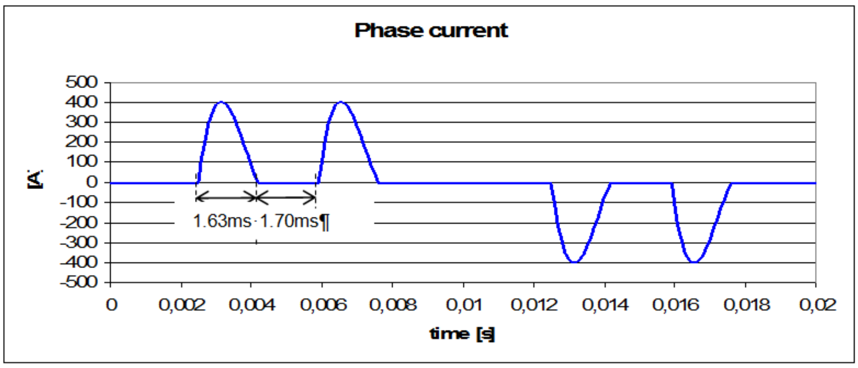


Figure 1

2 Snubbers

a) Draw an IGBTequipped step down chopper (buck converter) with an RCD snubber. The dclink voltage on the supply side is 200V and the load voltage is 150 V. Give a detailed description of how the RCD charge-discharge snubber should operate. Explain why the snubbers are needed (2 p.)

b) Calculate the snubber capacitor for the commutation time 0.015 ms. The load current is 9 A, assumed constant during the commutation. Calculate the snubber resistor so the discharge time (3 time constants) of the snubber capacitor is less than the IGBT on state time. The switch frequency is 2 kHz (4 p.)

c) Draw the main circuit of a flyback converter. The circuit should include DM-filter (differential mode) ,CM (common mode) filter, rectifier, dc link capacitors, alternative connection for voltage doubling connection, switch transformer (one primary and one secondary winding is enough), switch transistor, flyback diode and a simple output filter, The circuit should also include snubbers. (2 p.)

d) The snubbers in the flyback converter shall reduce the effect of the magnetic energy stored in different stray inductances. For each snubber you must tell where the magnetic energy is found. Describe in detail how the current is flowing in the snubber and the voltages n the snubber (2 p.)

3 Three phase system

a) A symmetric three phase voltage:

$$\begin{cases} e_a = \hat{e} \cdot \cos(\omega \cdot t) \\ e_b = \hat{e} \cdot \cos\left(\omega \cdot t - \dfrac{2\pi}{3}\right) \\ e_c = \hat{e} \cdot \cos\left(\omega \cdot t - \dfrac{4\pi}{3}\right) \end{cases}$$

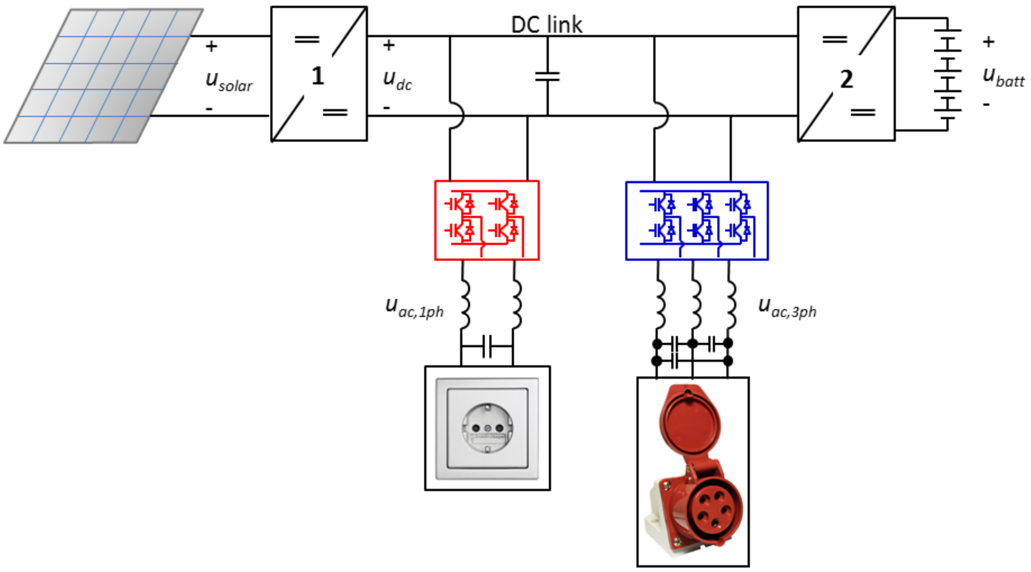
Show that these voltages form a rotating vector with constant length and constant speed in the complex (α,β) frame. (5 p.)

b) Draw the circuit of a PIE current control system with Carrier Wave modulation for a generic three phase RLE load. The drawing shall include three phase inverter, reference and load current measurement. It must be clear in which blocks the different frame transformations occur. (5 p.)

4 Modulation and Current Control

A house is equipped with a solar cell system and a battery storage system. The solar cell and the battery system are both connected to the same DC-link via a DC/DC-converter each. DC/DC converter 1 adapts the solar cell system voltage u_{solar} to the common DC link voltage u_{dc} and DC/DC converter 2 adapts the battery voltage u_{batt} to the same DC link voltage.

- The maximum solar cell system voltage u_{solar} and the maximum battery voltage u_{batt} are always lower than the DC link voltage u_{dc}.
- From the DC link, two separate converters are supplying normal AC voltages to loads in the house, according to the figure below.
- The RMS-value of the one-phase voltage $u_{ac,1ph}$ is 230 V and the RMS-value of the phase-to-phase voltage of the 3-phase supply $u_{ac,3ph}$ is 400 V.
- Both loads use 2nd order Low Pass Filters to dampen the harmonics from the two converters.
- The battery voltage u_{batt} = 350 V.



a) What is the absolute minimum DC link voltage needed to at the same time supply both AC loads (1ph and 3ph) ? Motivate your answer! (1p)

b) Expressed in terms of Quadrants, which are the simplest forms of DC/DC converters 1 and 2 in the figure? Draw the circuit diagram of both of them, including required passive components like inductors and make it clear which side of the converters is connected to the DC link. (2p)

c) Assume that the lowest harmonic in the output voltages of the two converters providing AC to the loads is 10 kHz. What is then the lowest modulation frequency required and what are the requirements on the modulation (symmetry etc…)? (1p)

d) Assume that the battery current (supplied to the terminals of the battery) is controlled with PIE-control and carrier wave modulation. Draw the circuit diagram of DC/DC-converter 2, with passive components and the battery and a block diagram of the control system including modulation. Make a diagram with a few periods of the modulating wave with the levels and period times of the modulating wave clearly noted including the sampling time instants used for current control of the battery current. (3p)

e) Based on your answer in a) and d), draw the voltage reference together with the modulating wave in one diagram and the current with ripple in another diagram for a current step response from 0 to a battery charging current corresponding to 5 kW battery charging power. Assume that the step response requires three sampling periods to complete the current step. The reference voltage level before, during and after the current step should be correctly drawn together with the modulating wave. The current ripple should be drawn with correct timing relative to the modulating wave and the right proportions between the positive and negative flanks of the current ripple. (3p)

5 PM Synchronous Machine

A permanently magnetized synchronous machine is used as a traction motor in an electric vehicle.

a) What shape (profile) must the rotor have for the reluctance torque to contribute to the total torque if positive torque is produced with the stator current vector in the 2'nd quadrant? Draw a rotor geometry that explains the principle. (5p)

b) Sketch the locus (in principle) of the stator current vector for maximum Torque/Current-ratio for the three cases (Lsx>Lsy, Lsx=Lsy and Lsx<Lsy). (5p)

-- Lycka till ! --

Some formulas:

Power Invariant vector definition:

$$\vec{s} = s_\alpha + js_\beta = \sqrt{\frac{2}{3}}\left[s_a + s_b e^{j\frac{2\pi}{3}} + s_c e^{j\frac{4\pi}{3}}\right] = \sqrt{\frac{3}{2}}s_a + j\frac{1}{\sqrt{2}}(s_b - s_c)$$